



Influence of manure, phosphate fertilizer and lime on soil available NPK and uptake of NP by soybean in Embu county, Kenya

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ABSTRACT

Soybean (*Glycine max* (L.) Merrill) is one of the most important legume crops being introduced into the smallholder farming systems of the Central Highlands of Kenya (CHK) for soil health improvement, income and improved household nutrition. However, phosphorus fixation, depletion of soil nutrients and soil acidity are major causes of low crop nutrition and yields. In order to study

the effects of organic and inorganic soil amendments on soil available phosphorus (P) and its uptake by soybean a study was conducted at Embu County. The study consisted of 8 treatments: manure (0, 5 and 10 ton.ha⁻¹), lime (0 and 2 t.ha⁻¹) and P fertilizer (0, 30 and 60 kg P₂O₅ ha⁻¹). The experiment was laid out in a Randomized Complete Block Design (RCBD) with 4 replicates in plots of 4x4.5m. Lime contributed significantly to increase soil available P relative to pre-season. Manure combined with P fertilizer and both P fertilizer plus lime mostly increased P uptake by 153.2 % and 148.4% respectively. These results showed the potential role of lime, manure and P fertilizer in improving soil available P and increase its uptake. Therefore, it is recommended to farmers in the CHK to adopt the integrated use of phosphatic fertilizers along with lime to enhance nutrient availability, uptake and yields.

Keywords: Manure, Lime, P fertilizer, Available NPK, NP uptake.

Abbreviations: ISFM (Integrated Soil Fertility Management), SR (Short Rain), LR (Long Rain), ANOVA (Analysis of Variance), SAS (Statistical Analysis Software).

1. INTRODUCTION

Smallholder farmers in the central highlands of Kenya (CHK) face problems of declining soil fertility due to intensive cultivation, nutrient removal via crop harvest and soil erosion on steep slopes (Sanchez & Jama, 2002). Use of commercial fertilizers to address the declining soil fertility remains minimal due to farmer's low income, which limits their ability to purchase fertilizers. According to several authors (Heisey & Mwangi, 1996; Makokha et al., 2001) high costs of fertilizer, lack of credit, delays in delivery of fertilizer due to poor transport and marketing infrastructure, lack of know-how about their usage, have individually or jointly constrained fertilizer optimal use (Heisey & Mwangi, 1996; Makokha et al., 2001). Several researchers have therefore recommended Integrated Soil Fertility Management (ISFM) options for increasing soil fertility and agronomic efficiency of applied inputs (Sanginga & Woomer, 2009; Vanlauwe et al., 2010).

Soybean, a native of China, is one of the legumes being integrated into the smallholder farming systems of the CHK. Soybean has a high commercial value and high concentration of protein (about 40%), calcium, phosphorus, fiber, and in addition, it is cholesterol free (Hassan et al., 2010). It plays an important role in providing rich food, cash and animal feeds (Mugendi et al. 2010; Chianu et al., 2009). Soybean, like other leguminous crops has a positive impact on the soil. The canopies of soybean cover the soil and protect it from recurrent erosion (Latif et al., 1992), has potential to fix N from the atmosphere through biological fixation (Nieuwenhuis & Nieuwelink, 2002). This is important in farming systems where soils are continuously been exploited since the increasing population demands for higher food production.

Despite the high interest in promoting soybean production due to its importance in supply of protein rich food, income and improving household nutrition (Chianu et al., 2009; Mugendi et al., 2010), its yields are relatively low not going beyond 800kg ha⁻¹ (Mahasi et al., 2010). The region is characterized with humic nitisol soil class with moderate to strong acidity, which results in high phosphorus fixation (Kanyanjua et al., 2002; Mugwe et al., 2007). The prevalence of acidity is associated with Nitrogen (N), Phosphorus (P) deficiency in the soil, Aluminum (Al) toxicity, low exchangeable bases (Ca, Mg, K and Na), and reduced microbial activity therefore low crop yield and land productivity (Crawford et al., 2008). Phosphorus, N and K are important plant nutrients used for early root development, growth, energy transfer and grain filling. However, under acidic soil conditions their availability is reduced resulting in low yields.

Animal manures have been used to provide plant nutrition, and have been reported to raise soil pH by liming effect (Maerere et al., 2001). On the other hand, liming acid soils tends to increase soil pH and consequently P availability. Mineral P fertilizer alone contributes to supply of P to crops. Although, studies have proven that combined application of organic and inorganic soil amendments and fertilizers improve nutrient use efficiency, yields and to some extent farmer's income (Danga et al., 2009). Therefore, this study aimed for evaluating the effects of goat manure, lime and phosphate fertilizer on soil available NPK and NP uptake by soybean grown in acid humic nitisol of Embu County located in the Central Highlands of Kenya.

2. MATERIAL AND METHODS

2.1. Site description

The experiment was carried out at Embu Agricultural Training College (Embu-ATC), located in Embu County (0°35' 25.58"S and 37° 25' 31.84"E) in Kenya. The site is at an elevation of 1494 m above sea level, with annual temperature of about 20° C and annual rainfall of 909 - 1230 mm (Jaetzold et al., 2006). The rainfall is bimodal with two seasons; long rains (LR) from March to June and

Short Rains (SR) from October to January. The soils are mainly humic Nitisols (Jaetzold et al., 2006), which are deep, well weathered with moderate to high inherent fertility but over time soil fertility has declined due to continuous mining of nutrients without adequate replenishment. Recent studies revealed that low levels of organic carbon (< 2.0%), nitrogen (<0.2 %), phosphorus (< 10 ppm) and range from moderate to strongly acidic (pH ranges from 4.8 – 5.4), conditions that result in low crop production (Mugwe, 2007). The district is a predominantly maize growing zone with small land holdings ranging from 0.1 to 2 ha with an average of 1.2 ha per household.

The area is characterized by rapid population growth, low agricultural productivity, increasing demands on agricultural resources and low soil fertility. The farming systems are complex consisting of an integration of crops trees and livestock with small farm holders that are intensively managed (Mairura et al., 2007). Land sizes are small ranging from 0.1 to 1.5 ha (mean=1 ha), and slope cultivation is widespread. Livestock production is a major enterprise especially improved dairy cattle breeds. Other livestock in the area include sheep, goats and poultry. Rainfall distribution during study period is presented in Figure 1.

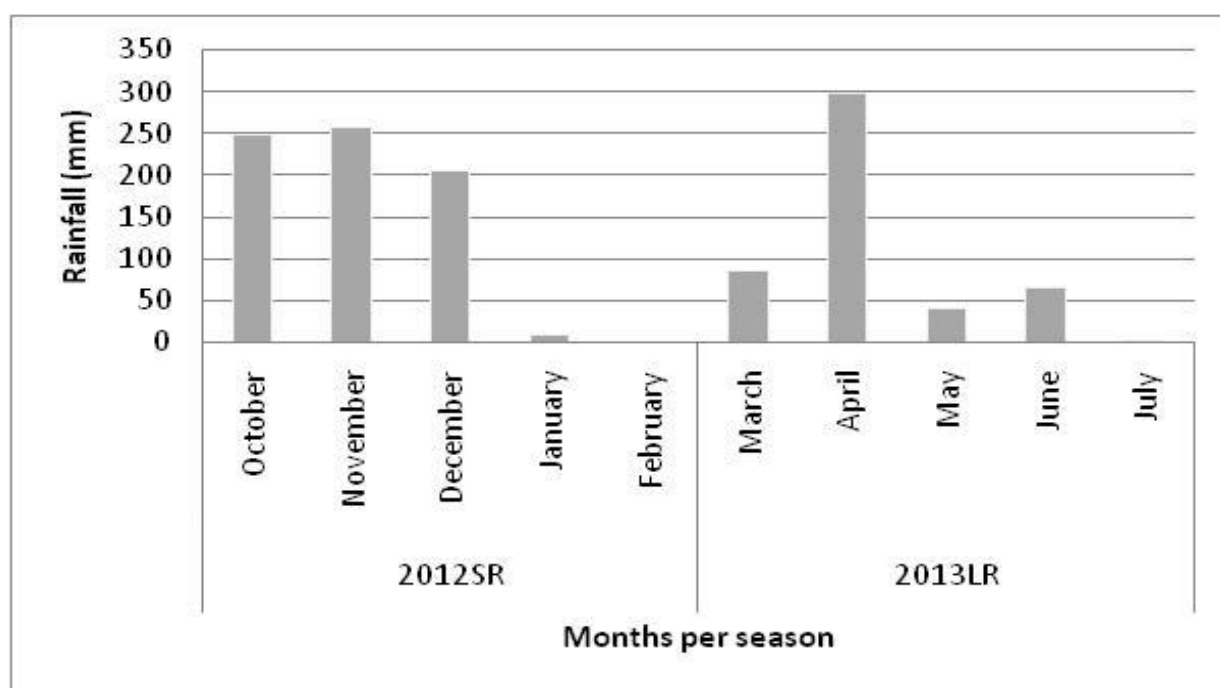


Figure 1 Amount of rainfall observed during study period at Embu, Kenya

2.2. Experiment design and field management

The experiment was a Randomized Complete Block Design (RCBD), with plots measuring 4.0x4.5 m and replicated four times. The experiment had 8 treatments and included: manure (M) (0, 5 and 10 t ha⁻¹ as goat manure); lime (0, 2 t ha⁻¹ as CaO) and P fertilizer (0, 30 and 60 kg P ha⁻¹) as Triple Super Phosphate (TSP). The treatments are presented in Table 1.

Table 1 Treatments and their description

Treatments	Description	Abbreviation
Manure	10 t ha ⁻¹ M	M
Lime	2 t ha ⁻¹ CaO	L
P fertilizer	60 kg ha ⁻¹ P ₂ O ₅	P
½Manure+Lime	5 t ha ⁻¹ M + 2 t ha ⁻¹ CaO	ML
½Manure+½ P	5 t ha ⁻¹ M + 30 kg ha ⁻¹ P ₂ O ₅	MP
½Manure+Lime+½P	5 t ha ⁻¹ M + 2 t ha ⁻¹ CaO + 30 kg ha ⁻¹ P ₂ O ₅	MLP
Lime+½ P	2 t ha ⁻¹ CaO + 30 kg ha ⁻¹ P ₂ O ₅	LP

Control

| No inputs

| C

Land was ploughed manually using a hand hoe followed by leveling 2 weeks before planting. Manure and lime were broadcasted and then incorporated in the soil within 15 cm depth, using hand hoe 2 weeks before planting. TSP was applied per furrow and well mixed with the soil at planting. Soybean var. *Gazelle*, was sown on 13th October (2012) by placing 3 seeds per hole at 50cmx10cm spacing. Two weeks after emergence, the seedlings were thinned to 2 plants per hill. The crop was weeded using hand hoe, three times (vegetative, flowering and podding stages) each season. Insecticide Thunder was sprayed for insect and termites control twice during 2012 SR and thrice during 2013 LR. Weeding was done three times.

2.3. Soil sampling and analysis

Soil samples were collected before planting and at harvest. The samples were collected from 0-15 cm. The soil samples were analyzed for pH, available NP and K. Soil pH was measured in a 1:2.5 soil : water suspension using a pH meter model AD1000 (Okalebo et al., 2002). Soil mineral N was determined by flow injection method after extraction with 2M KCl. Available P and K were determined by Mehlich 1 method as described by Okalebo et al. (2002). The soils of the experimental site were moderately acidic (Kanyanjua et al., 2002) and moderately low in available P and total N (Table 2).

Table 2 Chemical properties of the soil (0-15 cm depth) prior to planting and quality of manure

Parameters	Soil	Manure
pH water (1:2.5)	5.06	9.3
pH KCl (1:2.5)	4.21	
Exchangeable acidity [cmol (p+) kg ⁻¹ soil]	3.72	
Exchangeable cations [cmol (p+) kg ⁻¹ soil]		
Ca ²⁺	0.63	0.92 %
Mg ²⁺	0.51	0.44 %
K ⁺	0.12	1.69 %
Na ⁺	0.14	0.43 %
Extractable P (mgkg ⁻¹ soil)	7.54	0.46 %
Total N (%)	0.21	1.60 %
Organic C (%)	2.12	21.3 %

2.4. Plant sampling and P uptake determination

Plants were sampled for analysis for P content in the tissues during 2012 SR. At maturity stage, ten plants were randomly sampled per plot, oven-dried at 65°C for 48 hours. Dried samples were then ground and passed through 0.5 mm sieve. Thereafter, N concentration was determined CN analyzer while P was by vanado-molybdate method (Okalebo et al., 2002; Sark & Hader, 2005). NP uptake (kg ha⁻¹) was calculated by the following formula:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration(\%)} * \text{Dry Matter yield(kg ha}^{-1}\text{)}}{100} \quad (1)$$

2.5. Data analysis

Data generated were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS) version 8. The means were subjected to Tukey at 95% of confidence to test means difference. Least Significance Difference (LSD) at 95% of significance level was used to separate means.

3. RESULTS

3.1. Soil pH

Soil pH was significantly influenced by the application of treatments in 2012 SR and 2013 LR (Table 3). In 2012 SR lime alone recorded the highest value (5.83) in soil pH and significantly increased (+0.72 units) this parameter over the pre-season. This was

followed by MLP treatment with a significant increase over the pre-season (+0.68 units). In 2013 LR the treatments followed similar trend where Lime alone recorded highest pH value and a significant increase (+0.8 units) over the pre-season; and was followed by MLP with +0.71 units increase relatively to the pre-season.

Table 3 Soil pH, 0-15 cm depth before planting and at harvest, Embu, Kenya

Treatments	pH water (1:2.5)						
	Before	2012SR	Change	<i>t</i> -test, <i>p</i>	2013LR	Change	<i>t</i> -test, <i>p</i>
Manure	5.10 ^a	5.62 ^{ab}	+0.52	0.0025	5.72 ^{bc}	+0.62	0.004
Lime	5.11 ^a	5.83 ^a	+0.72	0.0019	5.91 ^a	+0.8	0.0011
P fertilizer	5.07 ^a	5.26 ^{cd}	+0.19	0.0321	5.26 ^e	+0.19	0.0358
½ Manure+Lime	5.02 ^a	5.64 ^{ab}	+0.62	<0.0001	5.65 ^c	+0.63	<0.0001
½ Manure+½ P	5.10 ^a	5.46 ^{bc}	+0.36	<0.0001	5.50 ^d	+0.4	<0.0001
½ Manure+Lime+½ P	5.11 ^a	5.79 ^a	+0.68	0.0116	5.82 ^{ab}	+0.71	0.0098
Lime+½ P	5.01 ^a	5.59 ^{ab}	+0.58	0.0014	5.70 ^c	+0.69	0.0005
Control	5.00 ^a	5.05 ^d	+0.05	0.7924	5.10 ^f	+0.1	0.4329
<i>p</i>-value	0.5718	<0.0001			<0.0001		
LSD(0.05)	0.15	0.27			0.1		

3.2. Soil available N, P and K

Soil available N values showed statistically significant differences in both 2012 SR and 2013 LR seasons (Table 4). During the both seasons the application of M treatments recorded the highest values for available N of 22.35 mg kg⁻¹ and 17.58 mg kg⁻¹ in first and second season, respectively. The lowest values were recorded for P (14.08 mg kg⁻¹) in 2012SR and ML (13.25 mg kg⁻¹) in the 2013 LR season.

Soil available P was improved (Table 4). In 2013 LR, application of P, M and L treatments recorded the highest increase by 48%, 37.9% and 35.1% respectively over the control. The lowest increase was recorded in the plots receiving MP (30.86 %) treatment. Relative to pre-season (Table 5), lime alone increased significantly soil available P (2+.91 units), followed by LP (+2.78), MLP(+2.64) and MP (+2.44).

Manure alone recorded the highest significant value of 0.30 and 0.41 cmol(p+) kg⁻¹ soil in 2012SR and 2013LR, respectively. MP (0.18 cmol(p+) kg⁻¹ soil) followed this in 2012SR and MLP (0.22 cmol(p+) kg⁻¹ soil) in 2013LR. LP was the lowest in 2012SR and control in 2013LR.

3.3. Soybean N and P uptake

The effects of treatments on N and P uptake are presented in Table 6. N uptake was significant in grain (*p* = 0.0011) and crop (*p* = 0.0012). Grain and crop N uptake were higher under MP 163.33 kg N ha⁻¹ and 197.18 kg N ha⁻¹, respectively. Application of P fertilizer alone did not affect significantly N uptake in both the grain and crop. It recorded the lowest values of 71.38 kg N ha⁻¹ and 99.01 kg N ha⁻¹, respectively.

The grain P uptake was significantly affected by the application of the treatments (*p* = 0.0022). Application of P alone recorded the highest significant P content in the grain (0.46%) over the control. The lowest was recorded under the ML (0.34%). The treatments also affected significantly grain P uptake (*p* = 0.0432) and total soybean P uptake (*p* = 0.0348). The application of MLP mostly increased grain P uptake by 3.13 times while MP mostly increased total P uptake by 2.53 times over the control. P treatment less increased the P uptake in both grain (1.66 times) and crop (1.41 times).

Table 4 Soil available N, P and K (0-15cm depth) at Embu, Kenya

Treatments	Available – N (mg kg ⁻¹)		Available – P (mg kg ⁻¹)		Available - K [cmol(p+) kg ⁻¹]	
	2012SR	2013LR	2012SR	2013LR	2012SR	2013LR
Manure	22.35	17.58	8.02	10.05	0.30	0.41
Lime	14.95	13.87	7.51	9.85	0.09	0.07
P fertilizer	14.08	13.74	7.35	10.79	0.09	0.08

½Manure+Lime	17.30	13.25	7.79	9.63	0.13	0.12
½Manure+½ P	17.25	14.08	7.36	9.54	0.18	0.17
½Manure+Lime+ ½P	16.13	14.30	7.32	9.58	0.15	0.22
Lime+½ P	15.78	14.84	7.24	9.84	0.07	0.11
Control	13.76	12.40	7.20	7.29	0.08	0.006
<i>p</i> -value	0.0238	0.0042	0.8995	0.0119	<0.0001	<0.0001
LSD _{0.05}	3.79	2.16	1.36	1.57	0.08	0.08

Table 5 Changes in soil available P (mg kg⁻¹) relative to the pre-season, 0-15cm depth at Embu, Kenya

Treatments	Pre-season	2012SR			2013LR		
		Harvest	Change	<i>t</i> test, <i>p</i>	Harvest	Change	<i>t</i> test, <i>p</i>
Manure	7.72 ^a	8.02 ^a	+0.30	0.9572	10.05 ^a	+2.33	0.1509
Lime	6.94 ^a	7.51 ^a	+0.57	0.4966	9.85 ^a	+2.91	0.0023
P fertilizer	8.15 ^a	7.35 ^a	-0.80	0.8073	10.79 ^a	+2.64	0.169
½Manure+Lime	8.45 ^a	7.79 ^a	-0.66	0.8051	9.63 ^a	+1.18	0.5297
½Manure+½ P	7.10 ^a	7.36 ^a	+0.26	0.7108	9.54 ^a	+2.44	0.0008
½Manure+Lime+½P	6.94 ^a	7.32 ^a	+0.38	0.3582	9.58 ^a	+2.64	0.0001
Lime+½ P	7.06 ^a	7.24 ^a	+0.18	0.8108	9.84 ^a	+2.78	0.0002
Control	7.93 ^a	7.20 ^a	-0.73	0.485	7.29 ^b	-0.64	0.5649
<i>p</i>-value	0.634	0.8995			0.0119		
LSD_(0.05)	2.05	1.36			1.57		

Table 6 Soybean N and P uptake at Embu, Kenya

Treatments	N uptake (kg ha ⁻¹)			P uptake (kg ha ⁻¹)		
	stover	grain	Total	stover	grain	Total
Manure	43.15	153.03	196.19	3.05	9.78	12.83
Lime	31.10	102.65	133.75	3.25	7.18	10.43
P fertilizer	29.82	76.57	106.39	2.65	5.55	8.20
½Manure+Lime	33.28	157.68	191.96	2.57	8.72	11.29
½Manure+½ P	33.86	163.33	197.18	4.58	10.13	14.71
½Manure+Lime+½P	34.52	143.25	177.77	3.94	10.49	14.43
Lime+½ P	37.23	109.16	146.39	3.77	7.07	10.84
Control	27.63	71.34	99.01	2.47	3.35	5.81
<i>p</i>-value	0.1415	0.0011	0.0012	0.1426	0.0432	0.0324
LSD_(0.05)	10.54	46.59	50.76	1.66	4.54	5.38

4. DISCUSSION

4.1. Soil pH

Soils with low pH ($\text{pH} < 5$) are usually of high concentration of H^+ and Al^{3+} ions in the solution, which affects negatively on nutrient availability for the crops. Lime alone and combined with manure increased soil pH. The increase was attributed to the addition of CaO content in lime, which reacts with water. Resulting production of OH^- ions took place which forms $\text{Al}(\text{OH})_3$ and H_2O thus raising the soil pH. In addition, the increase may be due to displacement of Al^{3+} and H^+ ions from soil sorption sites by Ca^{2+} ions content in lime. These results are similar to those of Kanyanjua et al. (2002), Kisinyo et al. (2012), Nekesa et al. (2005) who also reported increased soil pH with application of lime. Manure used was alkaline and fair in Ca, K, Mg composition. Therefore, released OH^- , Ca^{2+} , K^+ and Mg^{2+} ions may have contribute to complexation of Al^{3+} and H^+ ions in the soil. These results are par with the findings of several other researchers (Awodun et al., 2007; Adeniyani et al., 2011; Kheyrodin & Antoun, 2012).

4.2. Soil available N

Nitrogen is involved in cell division, photosynthesis, shoot and root development (Gupta, 2011). Its availability in the soil affects directly crop growth and development. Manure alone or combined affected significantly soil available N. It was attributed to release of N from manure through its mineralization plus the improvement of soil conditions for microorganism's development and activity as result of lime application. These results are consistent with those of Kihanda et al. (2004), Edmeades (2003), Kapkiyai et al. (1999) and Whalen et al. (2000) who also found that soil nitrates and mineral N were higher in manured soils. The higher values may be associated to the rate of manure applied. This is the fact that application of sole manure resulted highest soil available N.

4.3. Soil available P

The high available P observed under sole manure application in 2012 SR season was also reported by Abera et al. (2005) in Ethiopia. In 2012 LR there were small changes in soil available P even with application of P fertilizer. The small changes may be attributed to the fact that the soils were moderately acidic ($\text{pH} = 5.06$) yet considerable levels of P fixation expected. Fertilizer (P) application was placement while sampling was done between the rows. This, together with P immobility in the soil is known (Gupta, 2011) may explain poor P changes observed. According to Kamara et al. (2008), variability of soil available P after application of fertilizer may be due to fertilizer placement instead of broadcast. Furthermore, lime and manure effects require time to release soil fixed P and to mineralization take place. Another reason for this observation may be the uptake of P by the plants. According to Gudu et al. (2005) the crop P uptakes is another pathway or sink for the added P. These observations are in par with those of Abera et al. (2005), Kamara et al. (2008).

In 2013 season and when compared to preseason, lime alone or combined increased significantly soil available P. This was due to increased soil pH, which in return reduced P fixation and raised its availability in the soil. Liming acid soils raises soil pH releasing phosphate ions precipitated with Al and Fe ions rendering then available P for plant uptake (Chimidi et al., 2012). Manure effects on raising soil P availability may be attributed to (i) liming effects of manure which reduced P fixation (Onwonga et al., 2008), and (ii) to manure mineralization with release of P content in it (Toor, 2009).

4.4. Soil available K

The increase of soil exchangeable K under manured treatments was attributed to the K content in the manure used and released through mineralization. Other researchers (Ayeni & Adetunji, 2010; Adeniyani et al., 2011) reported also similar findings. The manure used in this study was of 1.69% in K content which may have added significant amounts of this nutrient to the soil. The highest increase in the plots receiving application of sole manure may be associated with the rate of manure applied, which supplied relatively more of this nutrient.

4.5. P uptake

Sole application of P and lime alone enhanced significantly P content in the grain, which may be due to the high rate of P applied. While lime may have improved soil acidity and released fixed P. Similarly, other researchers (Devi et al., 2012; Jahangir et al., 2009; Ogoke et al., 2004). According to Caires and Fonseca (2000) increased grain content even in the soils that have tested low in P is associated to P release when the pH is increased under lime application. In this study was found a strong, positive and significant relationship ($R^2 = 0.52$; $p = 0.0423$) between grain P uptake and soil pH (Figure 2). Despite the high P content observed in the grain under sole application of P and lime, the grain P uptake was low due to low dry matter produced.

Integrated application of manure with P fertilizer or with P plus lime had higher values of crop P uptake. Manure may have influenced the P uptake in different ways: i) improving soil acidity, ii) acted as nutrient source for the crop. Manure, when combined

with mineral fertilizer and lime it influenced the availability of nutrients through improved soil properties leading to higher crop growth and greater accumulation of biomass and consequently increased uptake. Schmitt et al. (2001) and Adeli et al. (2005) also found increased P uptake with application of manure alone or combined with mineral fertilizers. According to Schmitt et al. (2001) nutrient accumulation differences can be caused either by dry matter accumulation and or by plant nutrient concentration differences.

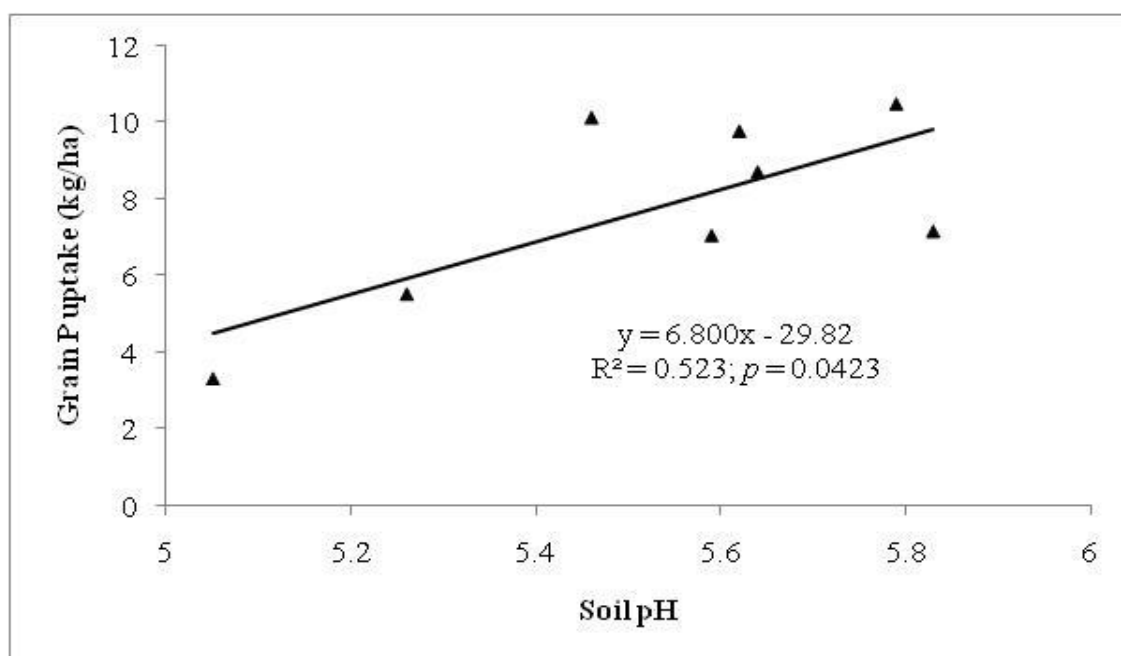


Figure 2 Relationship between grain P uptake and soil pH in 2012 SR

5. CONCLUSIONS

Lime is an important soil amendment to improve soil pH and promote not only better soil conditions but also its fertility status. Manure showed also to be important soil amendment to increase soil fertility by providing crop nutrient and contribute to increased nutrient uptake. However, integrated application of manure with lime and P fertilizer increased significantly soil chemical properties and nutrient uptake. It is recommended use of manure along with lime and mineral fertilizers for increased soil available NPK and uptake of NP by soybean in this region.

SUMMARY OF THE RESEARCH

1. The research was looking at the effects of manure, lime and P fertilizer on soil available NPK and NP uptake by soybean. The experiment comprised of 8 treatments including the control and was set in a RCBD in Embu County, Central Highlands of Kenya.
2. Despite lime and manure applied alone have shown their significant contribution in improving soil condition and nutrient availability their combination plus P fertilizer has greatly increased soil available NPK and NP crop uptake.

FUTURE ISSUES

Researchers and farmers should take into consideration the increasing importance of lime in an environment where soils are increasingly becoming acidic. Its combination with organic resources is relevant.

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